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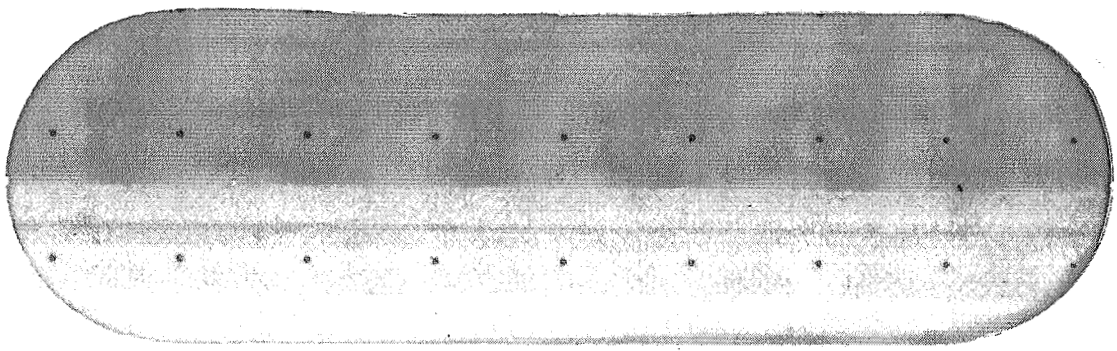

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VOLUME 1 OF 1

TITLE EFFECTS OF PROCESSING VARIABLES ON BOND STRENGTH OF POLYURETHANE ADHESIVE

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ABSTRACT

Laboratory tests and literature surveys were conducted to evaluate several processing variables with respect to our polyurethane adhesive bonding process, MSFC-SPEC-60B32067. Evaluated were variables such as bond line thickness, adherend etchant, and adherend primers. Findings indicate that: 1) room temperature peel adhesion will be improved by increasing the bondline thickness; yet room temperature lap shear and cryogenic peel and lap shear will not be significantly affected, 2) the present 60B32067 paste etchant formulation is satisfactory, and 3) the incorporation of a silane type primer or equivalent into the 60B32067 bonding process will significantly increase bondline resistance to moisture degradation.

KEY WORDS

Polyurethane Adhesive

Bondline

Adherend

Etchant

Primer

Lap Shear Strength

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SECTION 1

GENERAL PROGRAM OBJECTIVES, CONCLUSIONS AND RECOMMENDATIONS

1.0 OBJECT

To evaluate certain processing variables with respect to their effect on bond strength of polyurethane adhesive. ①

2.0 BACKGROUND

The process specification used on the S-IC booster stage for structural bonding with polyurethane adhesive is MSFC-SPEC-60B632067. In an effort to improve this process and increase reliability of bonded assemblies the following processing variables were evaluated as to their influence on bond strength: (1) Bondline thickness, (2) Type of paste etch used for adherend preparation.(3) Use of silane type adherend primer.

3.0 CONCLUSIONS

3.1 BONDLINE THICKNESS (SECTION 2)

Results from this study indicated that varying the bondline thickness from 1 to 20 mils, nominal, has no significant effect on room temperature lap shear strength. Literature data shows this same range has no significant influence on cryogenic lap shear strength; ② but, that room temperature peel increases with increasing bondline thickness. ③

3.2 ADHEREND PASTE ETHCANT (SECTION 3)

Results indicate that the present paste etch formulation per MSFC-SPEC-60B32067 is somewhat superior to the four others evaluated.

3.3 ADHEREND PRIMERS (SECTION 4)

Dow Corning's Z-6040 and Union Carbide's A-1100 silane type primer effected a significant reduction in bondline degradation resulting from a humid environment. Also, these primers noticeably increased the lap shear strength of ambient stored specimens.

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① The polyurethane adhesive used in this study was Narmco 7343/7139, available from the Whittaker Corporation.

② "Optimization of the Performance of a Polyurethane Adhesive System over the Temperature Range of -423°F to +200°F," Monthly Progress Report No. 5, Whittaker Corporation.

③ Ibid, Quarterly Report No. 2

4.0 RECOMMENDATIONS

4.1 BONDLINE THICKNESS (SECTION 2)

Change the MSFC-SPEC-60B32067 bondline thickness tolerances from 2-10 mils to 10-20 mils.

4.2 ADHEREND ETCHANT (SECTION 3)

Continue using the present 60B32067 paste etch formulation and application process.

4.3 ADHEREND PRIMERS (SECTION 4)

Revise the 60B32067 process specification to incorporate the use of a silane type (or equivalent) adherend primer. However, this should first be preceeded by further laboratory investigations to optimize the priming process.

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SECTION 2

EFFECTS OF BONDLINE THICKNESS ON ROOM TEMPERATURE LAP SHEAR STRENGTH

1.0 ABSTRACT

MSFC-SPEC-60B32067 has a nominal 2 to 10 mil bondline thickness requirement. Tests were conducted to show the effects, on room temperature lap shear strength, of thicknesses outside of this range. Average lap shear results showed no significant variation within the range of thicknesses (1 to 20 mils, nominal) evaluated.

2.0 PROCEDURE

2.1 ADHEREND PREPARATION

Lap shear adherends were made from 2219-T87 aluminum alloy to the configuration shown in MSFC-SPEC-60B32066. The adherends were cleaned and the Narmco 7343/7137 adhesive, per the above referenced specification, was mixed, applied and cured per MSFC-SPEC-60B32067. The bondline thicknesses of different test panels were varied by the use of cleaned stainless steel wire shims of the following nominal diameters: no shim, .005 inches, .010 inches, and .020 inches.

2.2 TEST CONDITIONS

Specimens were tested at ambient laboratory temperature (~78°F) at a loading rate of 1200 to 1400 pounds/minute in accordance with 60B32067. Tests were performed on a "BALDWIN 20K" (NASA # 045482) tensile test machine.

3.0 RESULTS

3.1 PRESENTATION OF DATA

Individual test values are shown in Table 2-II, attached. Average results are shown in Table 2-I, below.

3.2 EFFECTS OF BONDLINE THICKNESS ON ROOM TEMPERATURE LAP SHEAR STRENGTH

TABLE 2-I
SUMMARY OF BONDLINE THICKNESS VS. LAP SHEAR STRENGTH RESULTS

Nominal Bondline Thickness (inches)	Room Temp. Lap Shear Avg.	High	Low	N*
.001 (No shim)	1009	1160	950	7
.005 Shim	1086	1558	872	6
.010 "	1006	1245	745	10
.020 "	1166	1520	940	6

N = Number of specimens tested.

3.2 (Continued)

From the above tabulation it is apparent that the bondline thickness, within the range shown, had little influence on the average room temperature (RT) lap shear strength of Narmco 7343/7139 adhesive. In similar tests conducted by the Whittaker Corp. it was reported that RT lap shear decreased somewhat (in contrast to our findings) as bondline thickness increased from 1 mil to 20 mils and that -320°F lap shear strength was relatively unaffected. (1) Reference (2) shows that RT peel strength increased as bondline thickness increased from 4 to 20 mils while -320°F peel strength remained constant over this same range.

From the finding of this study and those reported by Whittaker it appears that a general purpose bondline thickness should be 10 to 20 mils. This would give more RT peel than the present 2 to 10 mil requirement and yet not decrease the cyrogenic peel or lap shear strength.

(1) "Optimization of the Performance of a Polyurethane Adhesive System Over the Temperature Range of -423°F to +200°F," Monthly Progress Report No. 5, Whittaker Corporation.

(2) Ibid, Quarterly Report No. 2

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TABLE 2-II

EFFECTS OF BONDLINE THICKNESS ON ROOM TEMPERATURE LAP SHEAR STRENGTH OF POLYURETHANE ADHESIVE (NARMCO'S 7343/7139)

SPEC. NO.	WIDTH (IN)	LAP (IN)	THICK-NESS (MILS)	LOAD (LBS)	STRESS (PSI)
		NO SHIM			
1	1.03	0.52	2.7	540	1018
2	1.01	0.51	1.2	530	1000
3	1.03	0.49	0.7	410	804
4	1.03	0.51	0.1	615	1160
5	1.01	0.49	0.3	555	1088
6	1.02	0.49	0.6	485	950
7	0.98	0.49	0.1	510	1042
AVERAGE			1.0		1009
		(.005 IN. SHIM)			
8	1.03	0.51	4.5	555	1090
9	1.03	0.51	4.9	580	1094
10	1.00	0.49	4.3	450	900
11	1.03	0.49	5.1	445	872
12	1.02	0.52	3.8	520	1000
13	1.01	0.52	4.5	810	1558
AVERAGE			4.5		1086
		(.010 IN. SHIM)			
14	1.03	0.51	12.0	570	1075
15	0.99	0.51	10.1	510	1020
16	1.02	0.50	9.4	515	1106
17	1.01	0.50	9.7	635	1245
18	1.02	0.50	10.0	600	1176
19	1.02	0.50	10.2	385	754
20	0.99	0.50	10.6	530	1060
21	1.02	0.50	10.6	440	862
22	1.00	0.50	10.9	465	930
23	1.03	0.50	11.2	440	830
AVERAGE			10.5		1006
		(.020 IN. SHIM)			
24	1.03	0.50	21.9	510	981
25	1.02	0.52	19.3	495	940
26	1.03	0.48	20.0	760	1520
27	1.02	0.48	18.3	500	1000
28	1.00	0.49	20.0	600	1200
29	1.02	0.49	20.0	690	1352
AVERAGE			19.1		1166

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SECTION 3

EFFECTS OF VARIOUS PASTE ETCHANTS ON ROOM TEMPERATURE LAP SHEAR STRENGTH

1.0 ABSTRACT

The present paste etch formulation called for in MSFC-SPEC-60B32067 was compared to four other formulations (on the basis of room temperature lap shear strength) to determine if a process change was warranted. The results indicate that the present formulation is satisfactory.

2.0 PROCEDURE

2.1 ADHEREND PREPARATION

Lap shear adherends were made from 2219-T87 aluminum alloy to to configuration shown in MSFC-SPEC-60B32066. The adherends were cleaned and the Narmco 7343/7139 adhesive was mixed, applied, and cured per MSFC-SPEC-60B32067 except the following paste etch formulations were used:

Type 1: Pasogel 101 ①
Type 2: Pasogel 105 ①
Type 3: Mixture of: Sodium Dichromate - 30 Parts by weight(PBW)
Distilled Water - 50 PBW
Concentrated Sulfuric Acid - 50 PBW
Silica Gel (Santocel C ②) - 10 PBW

Type 4: Mixture of: Sodium Dichromate - 4 PBW
Distilled Water - 30 PBW
Concentrated Sulfuric Acid - 10 PBW
Baymal Colloidal Alumina ③ - Use as required to give a non-flowable paste.

2.2 TEST CONDITIONS

Specimens were tested at ambinet laboratory temperature ($\sim 78^{o}$F) at a loading rate of 1200 to 1400 pounds/minute in accordance with 60B32067. Tests were performed on a "BALDWIN 20K" (NASA # 045482) Tensile test mcahine.

3.0 RESULTS

3.1 PRESENTATION OF RESULTS

Detailed test results are shown in Table 3-II, attached. A general analysis and summary of the results are presented below.

① Available from Semco Sales & Service , Inc. Los Angeles, Calif.
② Available from Monsanto Chemical Corporation.
③ Available from E. I. DuPont Industrial & Biochemical Department

3.2 EFFECTS OF VARIOUS PASTE ETCHANTS ON BONDSTRENGTH

TABLE 3-I

COMPARISON OF AVERAGE ROOM TEMPERATURE LAP SHEAR RESULTS OF SPECIMENS PREPARED WITH VARIOUS PASTE ETCH FORMULATIONS

	Lap-Shear Strenght - PSI			
Type Etch (1)	Avg.	High	Low	N
Type 1	416	520	300	10
Type 2	797	1273	612	10
Type 3	857	1069	634	10
Type 4	834	980	601	10
Paste etch per 60B32067	1000 (2)	1558	640	39

(1) See Section 2.1 for identification of etchants
(2) "Rounded-off average" of results obtained from Section 4 (Non-primed specimens)

The objective of this test was to improve bond strength by the use of a more optimum paste etch formulation. But, based on average results from the above tabulation, it appears that no change in the present formulation is warranted.

TABLE 3-II (page 1 of 2)

EFFECTS OF VARIOUS PASTE ETCHANTS ON ROOM TEMPERATURE LAP-SHEAR STRENGTH

SPEC. NO.	WIDTH	BOND LAP	THICK-NESS	ULT. STRENGTH LOAD	STRESS
	(IN)	(IN)	(MILS)	(LBS)	(PSI)
	(PASOGEL 101 PASTE ETCH)				
1	1.01	.50	2.8	180	360
2	1.01	.50	4.0	235	470
3	1.02	.50	3.8	240	470
4	1.02	.50	2.8	200	392
5	1.02	.49	2.5	250	490
6	1.02	.49	2.2	260	520
7	1.01	.49	1.5	185	370
8	1.00	.49	1.2	170	340
9	1.02	.50	1.1	230	450
10	1.01	.49	2.0	150	300
AVERAGE					416
	(PASOGEL 105 PASTE ETCH)				
11	1.02	.50	1.6	340	666
12	1.03	.50	1.5	370	725
13	1.02	.51	1.8	450	882
14	1.02	.51	1.4	675	1273
15	1.02	.50	1.5	440	862
16	1.01	.52	5.6	455	858
17	1.02	.50	1.8	325	637
18	1.00	.49	2.0	300	612
19	1.01	.48	1.9	375	750
20	1.03	.48	2.0	355	710
AVERAGE					797

TABLE 3-II (page 2 of 2)

EFFECTS OF VARIOUS PASTE ETCHANTS ON ROOM TEMPERATURE LAP-SHEAR STRENGTH

SPEC. NO.	WIDTH	BOND LAP	THICK-NESS	ULT. LOAD	STRENGTH STRESS
	(IN)	(IN)	(MILS)	(LBS)	(PSI)
	(PASTE ETCH WITH SILICA GEL)				
21	1.02	.49	4.2	545	1069
22	1.03	.51	2.8	500	943
23	1.01	.50	3.4	360	720
24	1.02	.51	2.6	330	634
25	1.00	.50	3.7	410	820
26	1.00	.53	2.0	455	892
27	1.01	.52	2.0	410	820
28	1.00	.52	1.7	470	921
29	1.00	.52	1.9	410	820
30	1.00	.52	2.0	475	931
AVERAGE					857
	(PASTE ETCH WITH COLLOIDAL ALUMINA)				
31	1.02	.51	1.8	500	980
32	1.01	.49	1.3	480	980
33	1.02	.51	1.0	435	837
34	1.02	.52	3.4	455	858
35	1.01	.50	3.5	450	900
36	1.02	.49	2.4	405	901
37	1.01	.50	2.0	305	601
38	1.02	.49	1.9	320	640
39	1.00	.49	2.0	370	740
40	1.01	.50	1.5	440	880
AVERAGE					834

SECTION 4

EFFECTS OF SILANE TYPE PRIMERS ON ROOM TEMPERATURE AND -320°F LAP SHEAR STRENGTH

1.0 ABSTRACT

Polyurethane adhesive bondlines are adversely affected by a humid environment. To minimize this effect and to give maximum bond reliability the incorporation of an adherend primer into MSFC-SPEC-60B32067 is considered necessary. A limited number of silane type primers were evaluated for this purpose. A-1100 and Z-6040 gave very favorable results but additional data will be required before finalization of a "primer process" applicable to 60B32067.

2.0 PROCEDURE

2.1 ADHEREND PREPARATION

Lap shear panels per MSFC-SPEC-60B32066 were bonded with Narmco 7343/7139 polyurethane adhesive in accordance with MSFC-SPEC-60B32067 except the adherend surfaces were spray-primed, after cleaning, with the following silane primer solutions:

1) 0.3% (by volume) of Union Carbide's A-1100 in absolute methanol.

2) 0.2% (by volume) of Dow Corning's Z-6040 in anhydrous denatured ethanol.

3) 0.2% (by volume) of Down Corning's Z-6020 in anhydrous denatured ethanol

4) Control - No primer

Each of the above primers were prepared immediately prior to application. The primed surfaces were air dried 2 hours at room temperature prior to application of the adhesive.

2.3 TEST CONDITIONS

Specimens were tested at ambient laboratory temperature ($\sim 78^{o}F$) and at $-320^{o}F$ per procedures is MSFC-SPEC-60B32066. The machine used was a "Baldwin 20K" (NASA #045482) tensile test machine.

2.2 SPECIMEN ENVIRONMENTAL EXPOSURE

One half of the specimens prepared for each of the conditions in Section 2.1 were humid aged in a condensing humidity chamber; the other half were stored under ambient laboratory conditions ($78^{o}F$ and 60% RH). Conditions for humid aged specimens shown in attached Tables 4 - II thru 4 - 4V were: 8 weeks at $100^{o}F$ and 100% RH; conditions for corresponding specimens shown in Tables 4-VI thru 4 - VII were: 30 days at $120^{o}F$ and 100% RH. All humid aged specimens were tested per Section 2.3 within four hours after removal from the humidity chamber.

3.0 RESULTS

3.1 PRESENTATION OF DATA

Table 4-I, below, summarizes and analyzes data extracted from Tables 4 - II thru 4 - VII, attached, which shows individual test values for the various conditions evaluated. Figures 4 - 1 thru 4 - 12, attached, show the room temperature and the -320°F "humid aged" specimens after testing.

3.2 DISCUSSION OF RESULTS

TABLE 4 - I

EFFECT OF SILANE TYPE PRIMERS ON POLYURETHANE ADHESIVE LAP SHEAR STRENGTH UNDER "HUMID AGED" VS."AMBIENT STORAGE"' CONDITIONS - AVERAGE LAP SHEAR VALUES (PSI) EXTRACTED FROM TABLES 4 - II THRU 4 - VII

	TEST TEMP. -320°F							TEST TEMP. AMBIENT ROOM TEMP.						
	HUMID AGED - 8 WKS				AMB. STORAGE 8 WKS.			HUMID AGED - 8 WKS				AMB. STORAGE-8 Wks.		
	PSI	P(1)	SR(2)	N(3)	PSI	P(1)	N(3)	PSI	P(1)	SR(2)	N(3)	PSI	P(1)	N(3)
A-1100 Primer	8592	480	74	5	11600	104	5	932	140	60	5	1542	86	5
Z-6040 Primer	9786	560	78	5	12514	120	5	1512	290	59	5	2546	208	5
Z-6020 Primer	2208	48	18	5	12008	111	5	144	170(4)	11	5	1305	58	5
No Primer	1490	---	26	4	5608	---	5	388	---	47	5	828	---	5
	HUMID AGED -30 DAYS				AMB. STORAGE-30 DAYS			HUMID AGED -30 DAYS				AMBIEWT SOTRAGE - 30 DAYS		
Z-6020 Primer	5438	160	49	5	11115	84	5	512	25(4)	25	5	2039	78	5
No Primer	2094	---	35	5	6040	--	5	642	---	57	5	1118	--	5

NOTES: (1) P = ~ % Shear > Corresponding Non-Primed Shear

(2) SR = % Strength Retained - Humid Aged as % of Ambient Storage

(3) N = No. of Specimens Tested

(4) "P" in this case = ~ % Shear < Corresponding Non-Primed Shear

3.2 (Continued)

Based on results from the above table it is apparent that, of the three primers evaluated, A-1100 and Z-6040 are the most capable of increasing lap shear strength and increasing bondline resistance to moisture degradation.

Comparison of the "humid aged" specimens, Figures 4 - 1 thru 4 - 12, shows that the Z-6040 and A-1100 primed specimen were the least affected by moisture. Z-6020 primed specimens were the most adversely affected; even more so, in general, than corresponding non-primed specimens. This is reflected by the results in Table 4-I.

Comparision of 8 week humid aged specimens to corresponding 30 day humid aged specimens (Table 4-I) indicates that a humid environment has a continuing determinal effect. However, in a similar but longer term humid storage study, the Whittaker Corporation reported that a general leveling off occurs after a serious initial loss of strength. ①

In summary, the data obtained from this study indicates that a humid environment has a significant adverse effect on polyurethane adhesive bond strength; but, that employment of the proper adherend primer can minimize this effect and, simultaneously, increase both room temperature and -320°F lap shear strength. The Whittaker Corporation reports favorable results along this same line ①. Therefore, in view of results from this study and from reference ① a process change to MSFC-SPEC-60B32067 to include a silane type primer or equivalent should be considered.

① "Optimimization of the Performance of a Polyurethane Adhesive System Over the Temperature Range of -423°F to +200°F", Annual Summary Report For the Period May 14, 1966 thru February 14, 1967, Whittaker Corporation Narmco Research & Development Division, San Diego, California.

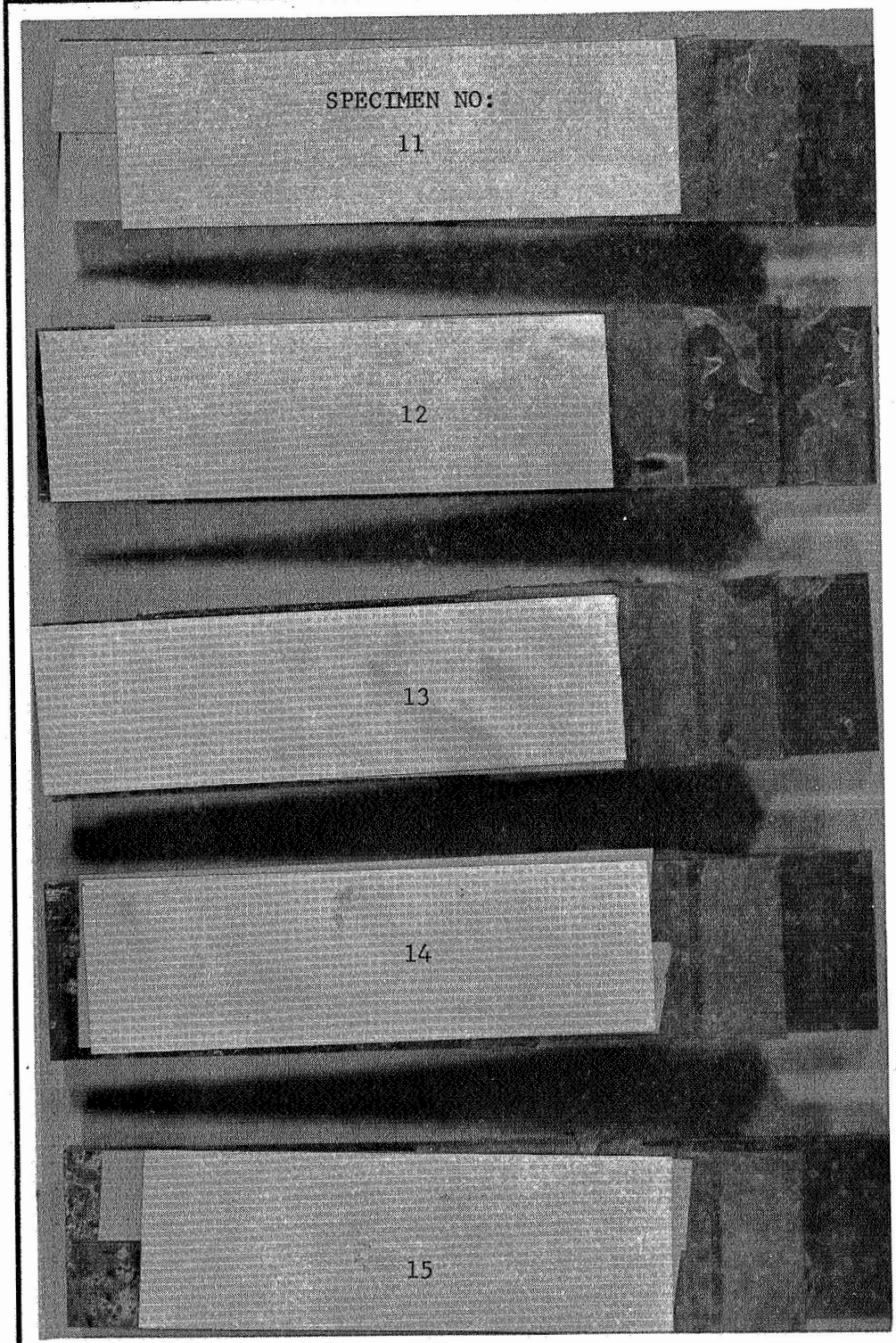

FIGURE 4-1

8 Week Humid Aged Specimens - Tested at Room Temp. - A1 Adherends Primed With A-1100 Silane & Bonded With Narmco 7343/7139 Polyurethane Adhesive.

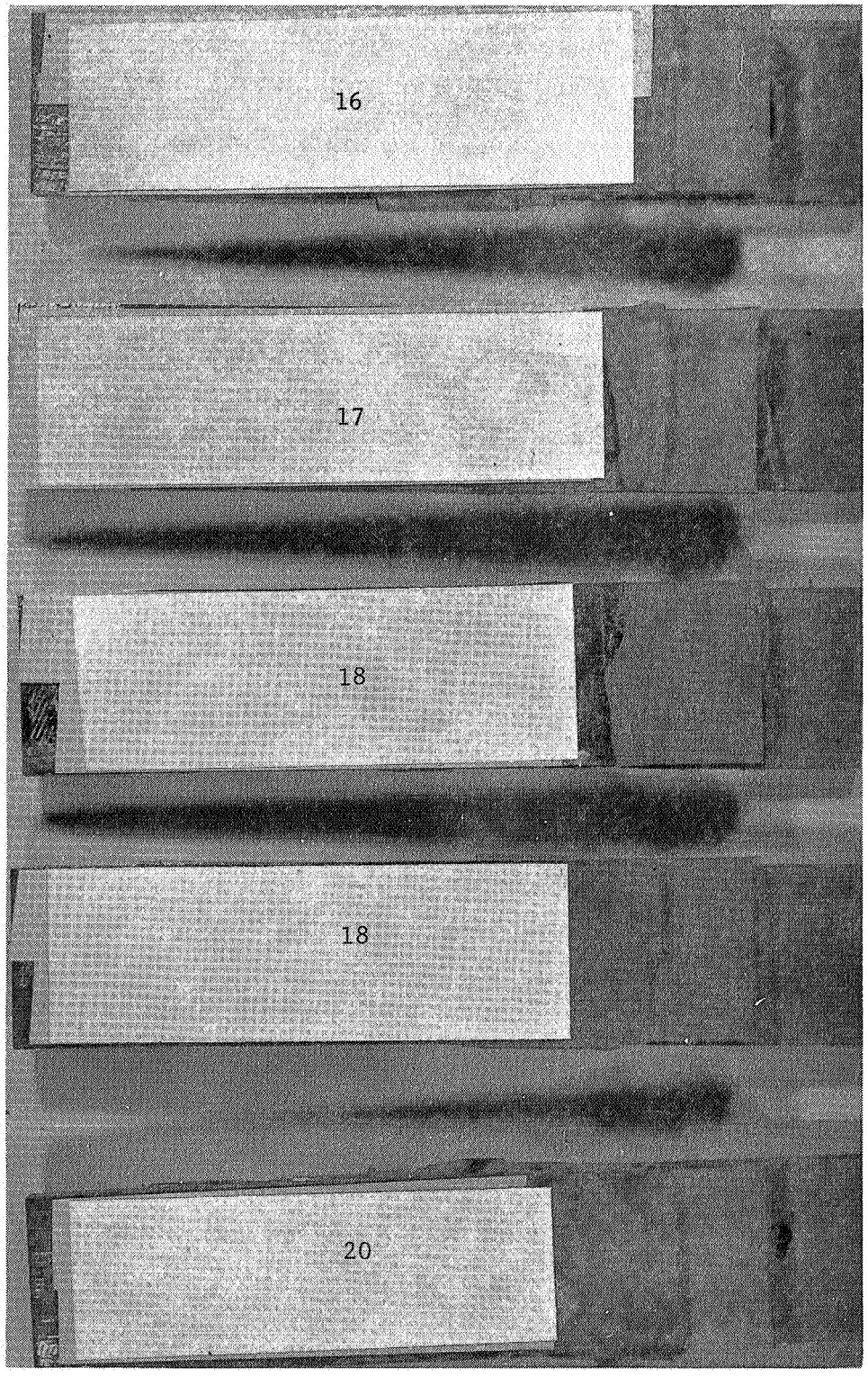

FIGURE 4-2

8 WEEKS HUMID AGED SPECIMENS - TESTED AT -320°F - AL ADHERENDS, PRIMED WITH A-1100 SILANE & BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE.

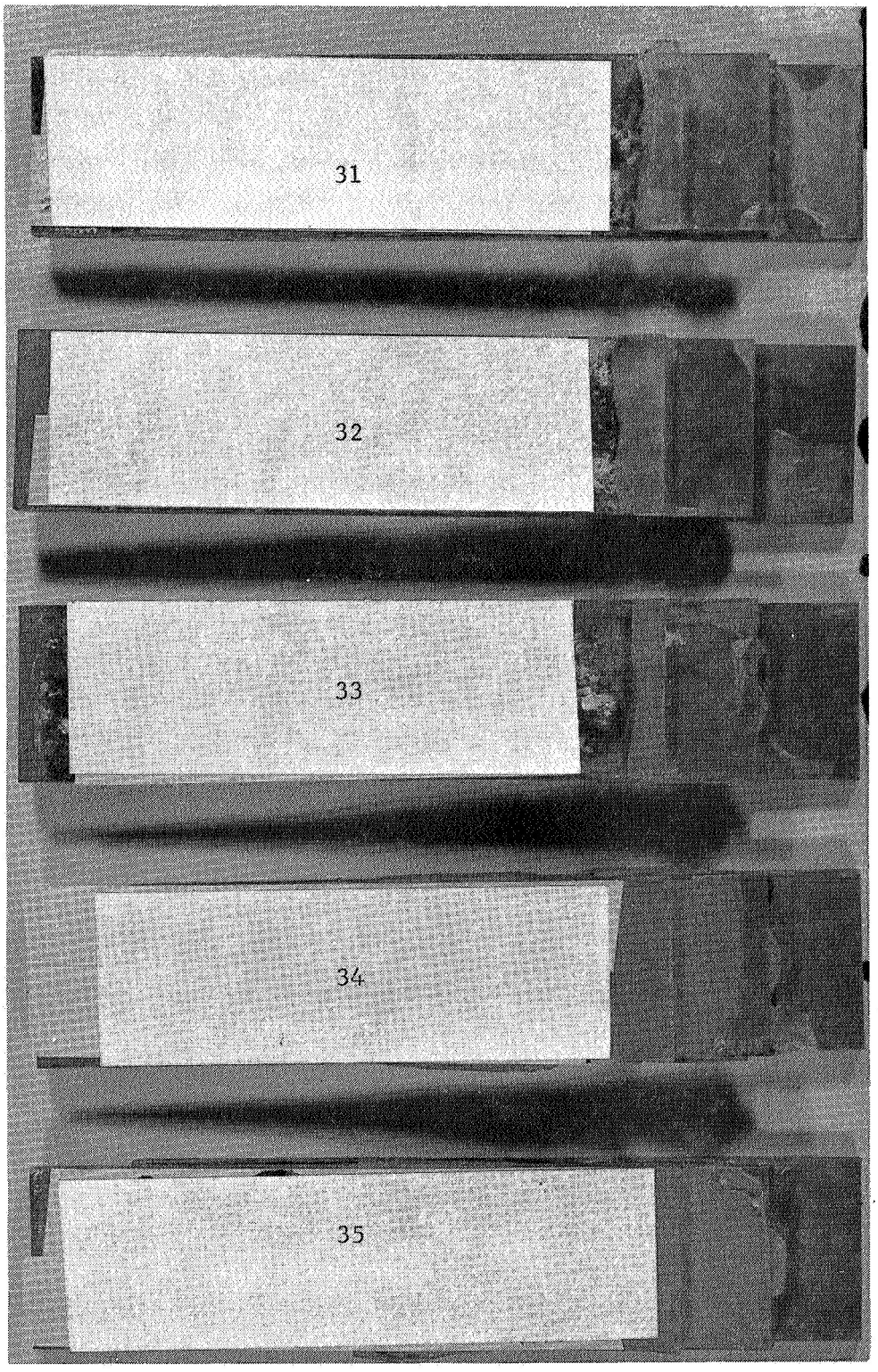

FIGURE 4-3

8 WEEKS HUMID AGED SPECIMENS - TESTED AT ROOM TEMPERATURE - AL ADHERENDS, PRIMED WITH Z-6040 SILANE & BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE

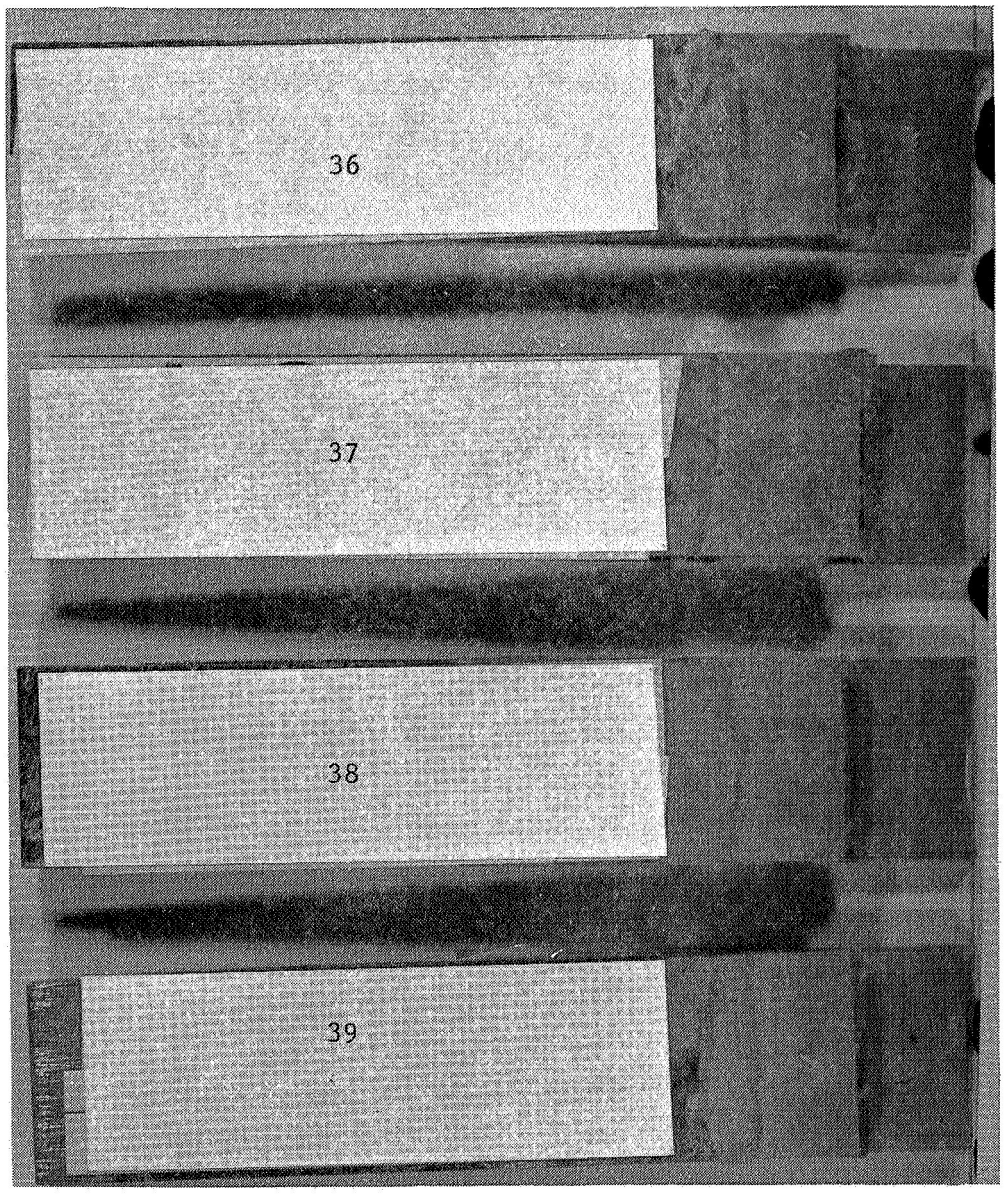

FIGURE 4-4

8 WEEKS HUMID AGED SPECIMENS - TESTED AT -320°F - AL ADHERENDS, PRIMED WITH Z-6040 SILANE & BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE.

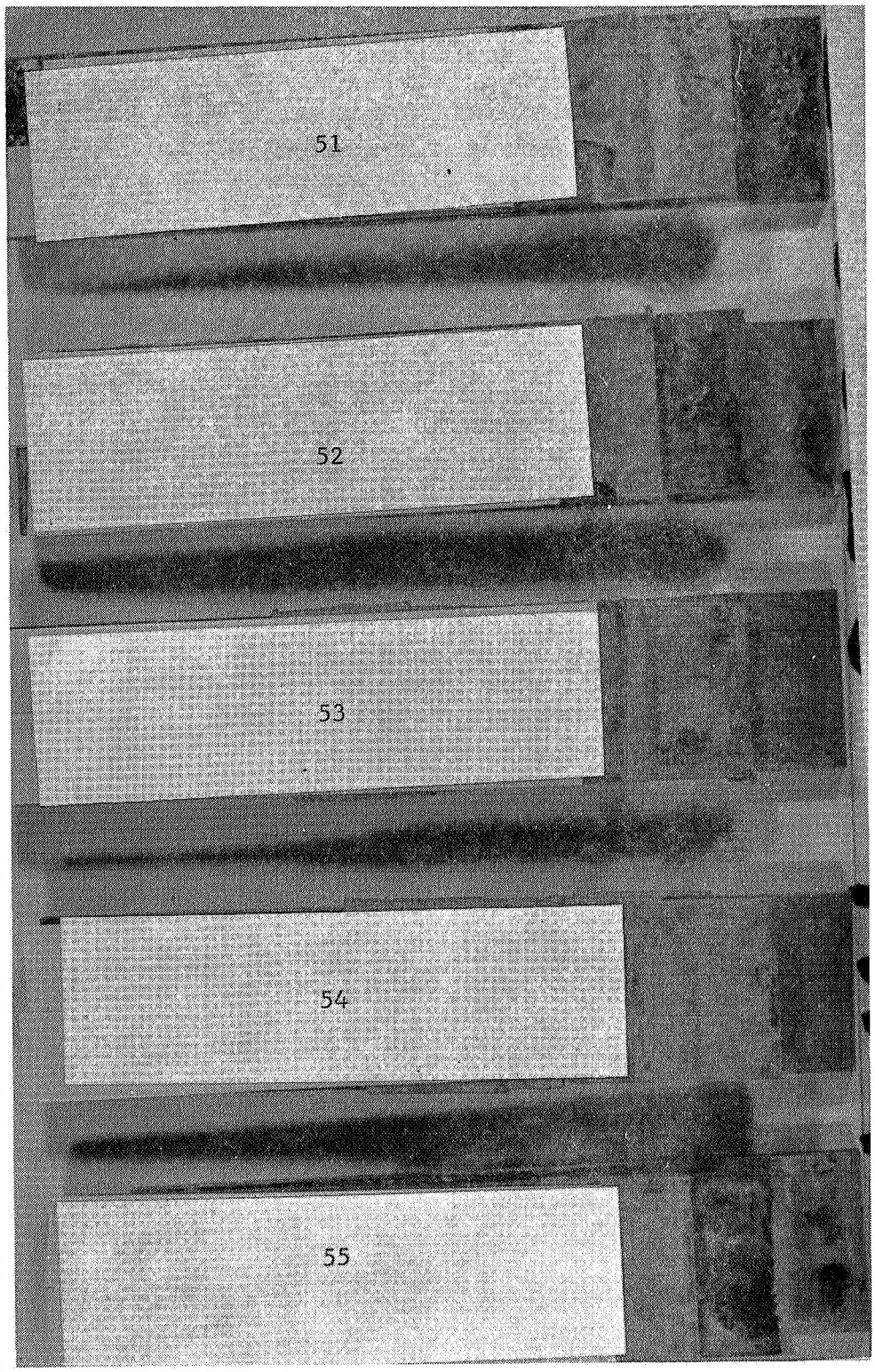

FIGURE 4-5

8 WEEKS HUMID AGED SPECIMENS - TESTED AT ROOM TEMP. - AL ADHERENDS, PRIMED WITH Z6020 SILANE & BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE.

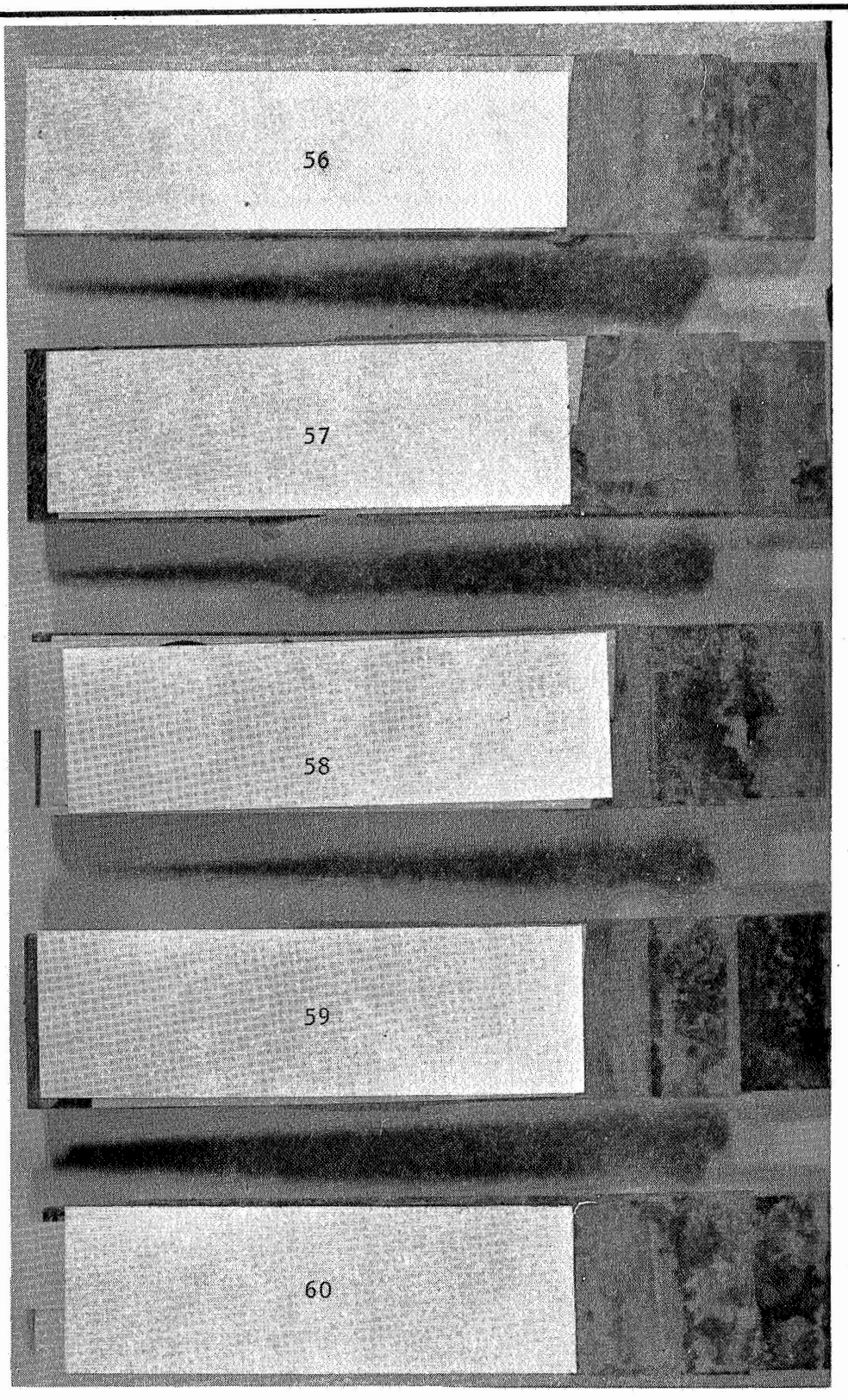

FIGURE 4-6

8 WEEKS HUMID AGED SPECIMENS - TESTED AT -320°F - AL ADHERENDS, PRIMED WITH Z-6020 SILANE & BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE.

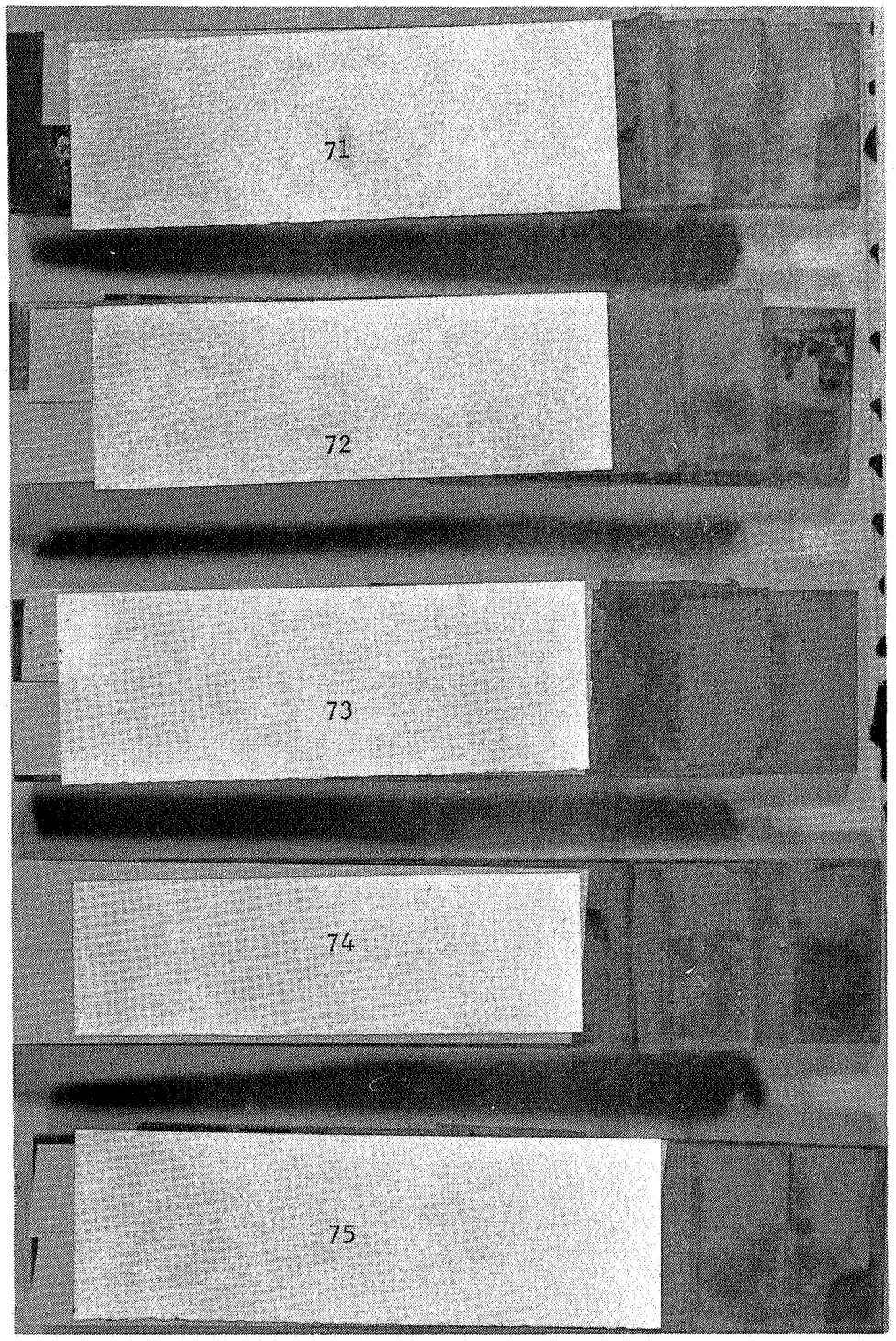

FIGURE 4-7

8 WEEKS HUMID AGED SPECIMENS - TESTED AT ROOM TEMPERATURE - AL ADHERENDS, NON-PRIMED, BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE

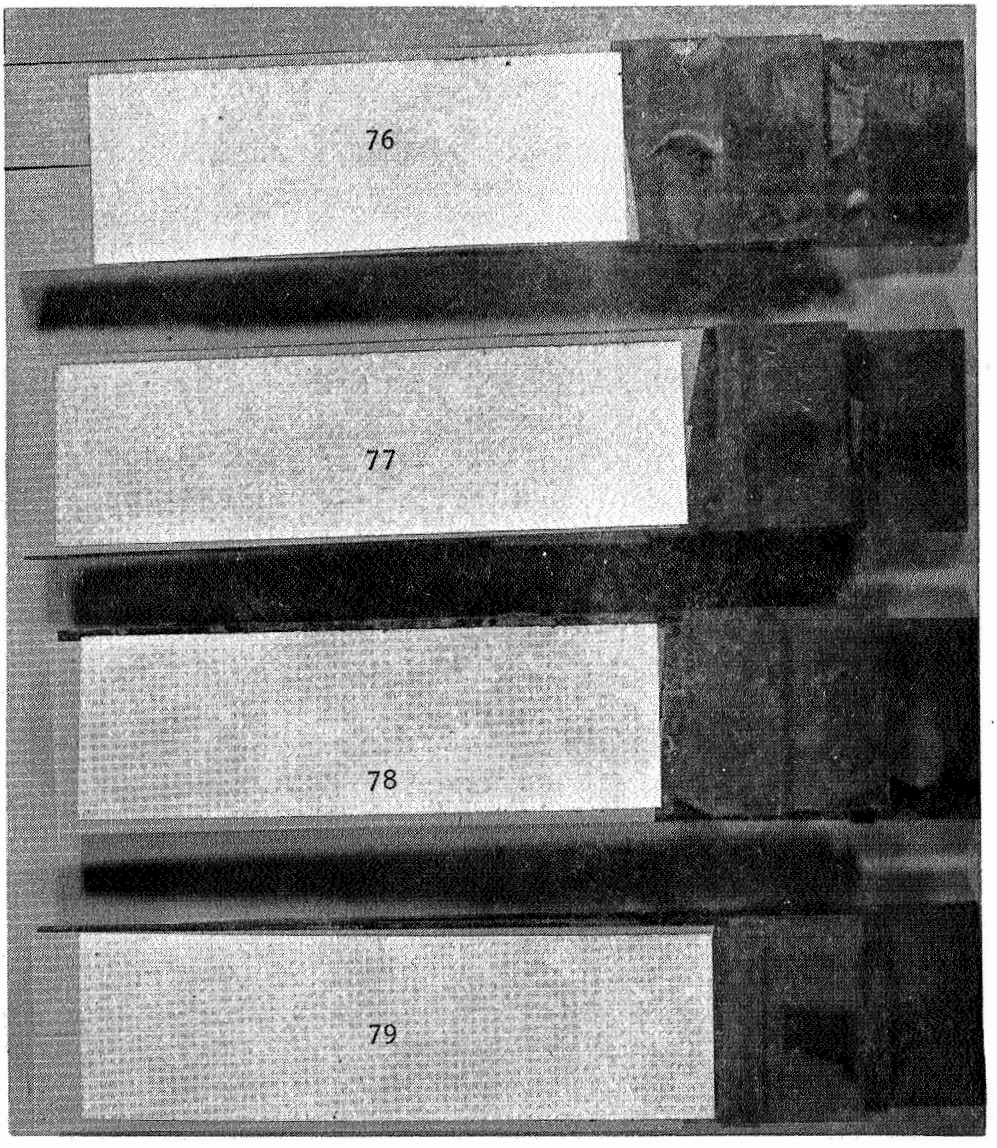

FIGURE 4-8

8 WEEKS HUMID AGED SPECIMENS - TESTED AT -320°F - AL ADHERENDS, NON-PRIMED, BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE

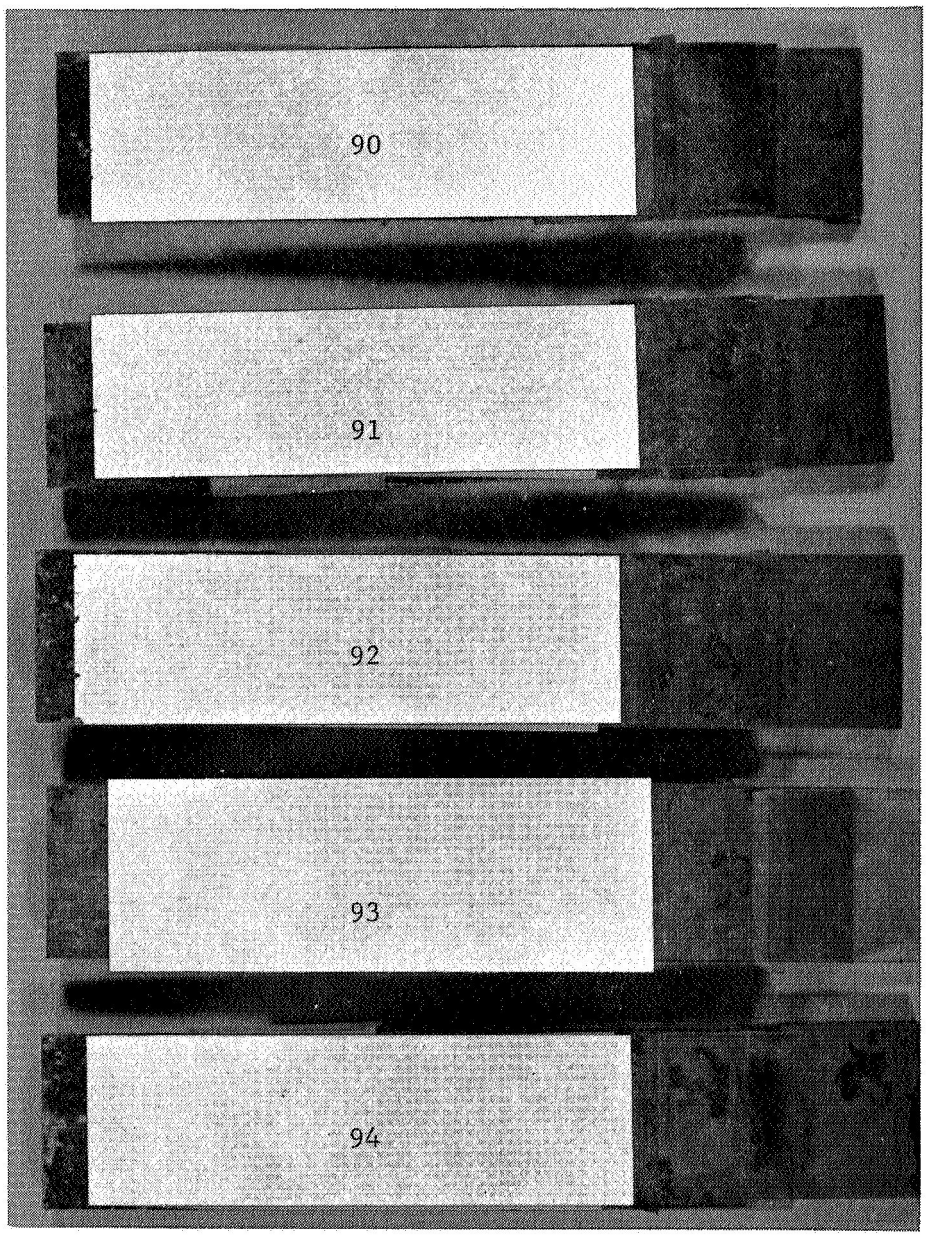

FIGURE 4-9

30 DAYS HUMID AGED SPECIMENS - TESTED AT ROOM TEMP. - AL ADHERENDS, PRIMED WITH Z-6020 SILANE & BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE.

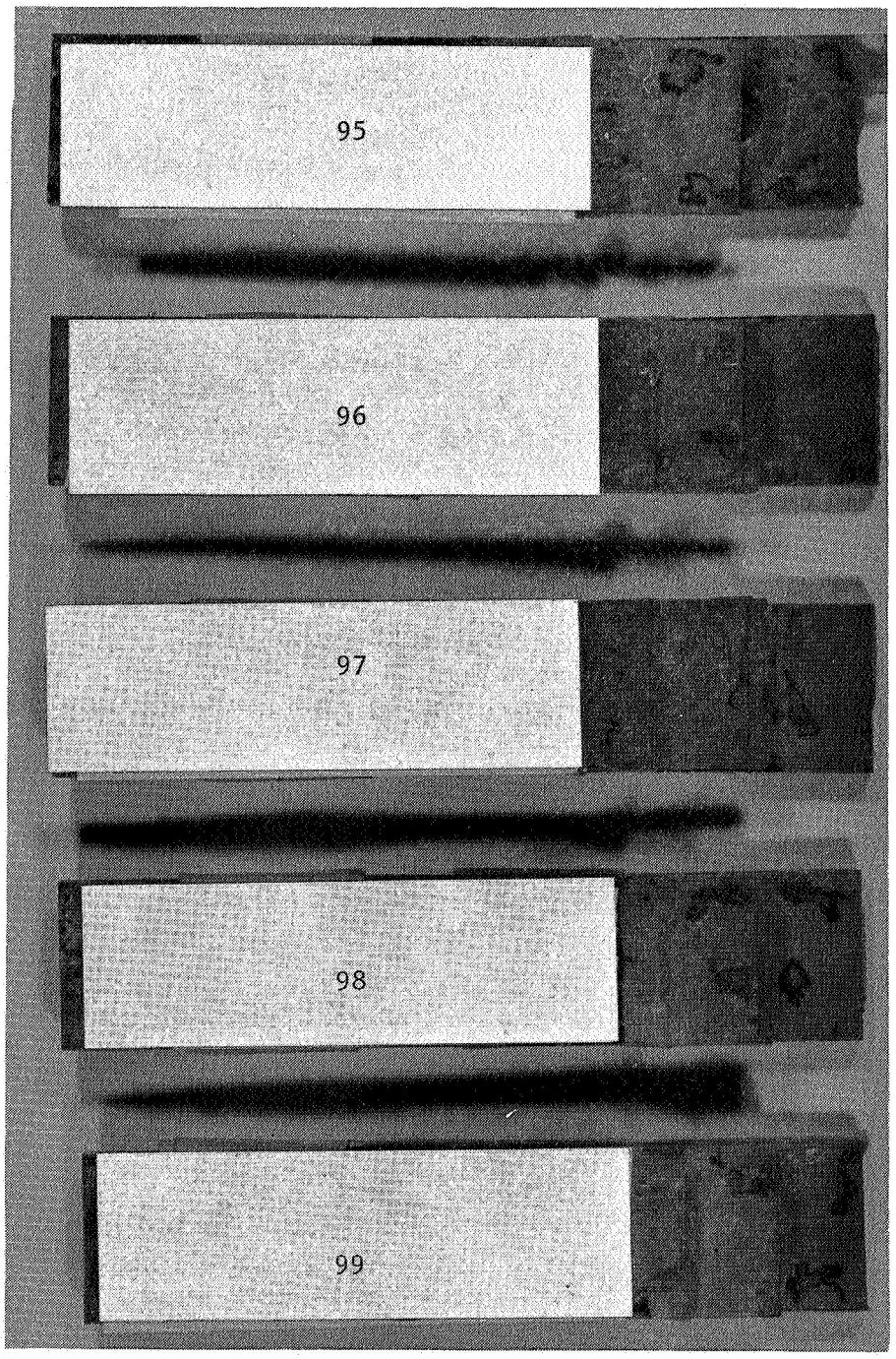

FIGURE 4-10

30 DAYS HUMID AGED SPECIMENS - TESTED AT -320°F - AL ADHERENDS, PRIMED WITH Z-6020 SILANE & BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE

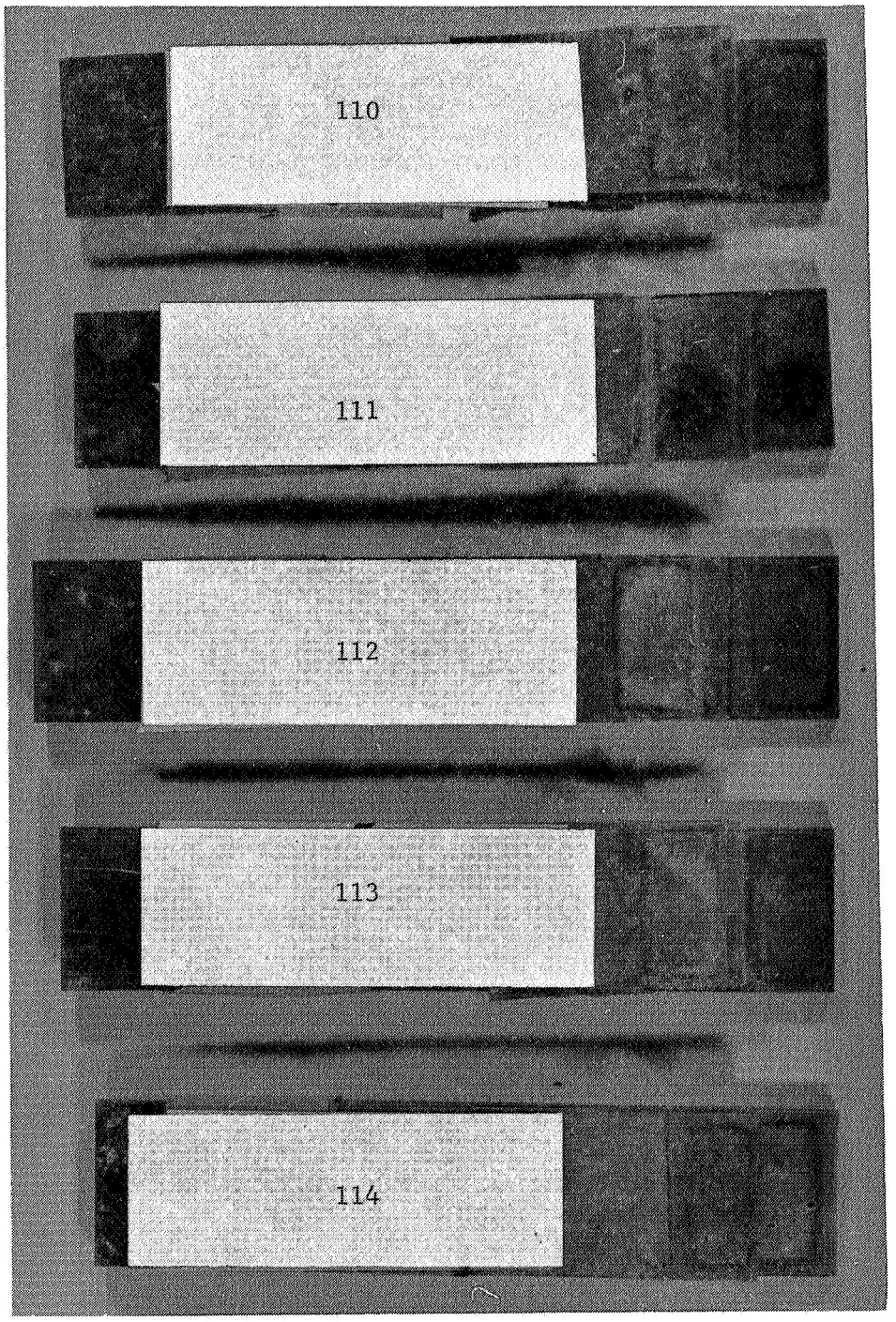

FIGURE 4-11

30 DAYS HUMID AGED SPECIMENS - TESTED AT ROOM TEMP. - AL ADHERENDS, NON-PRIMED, BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE.

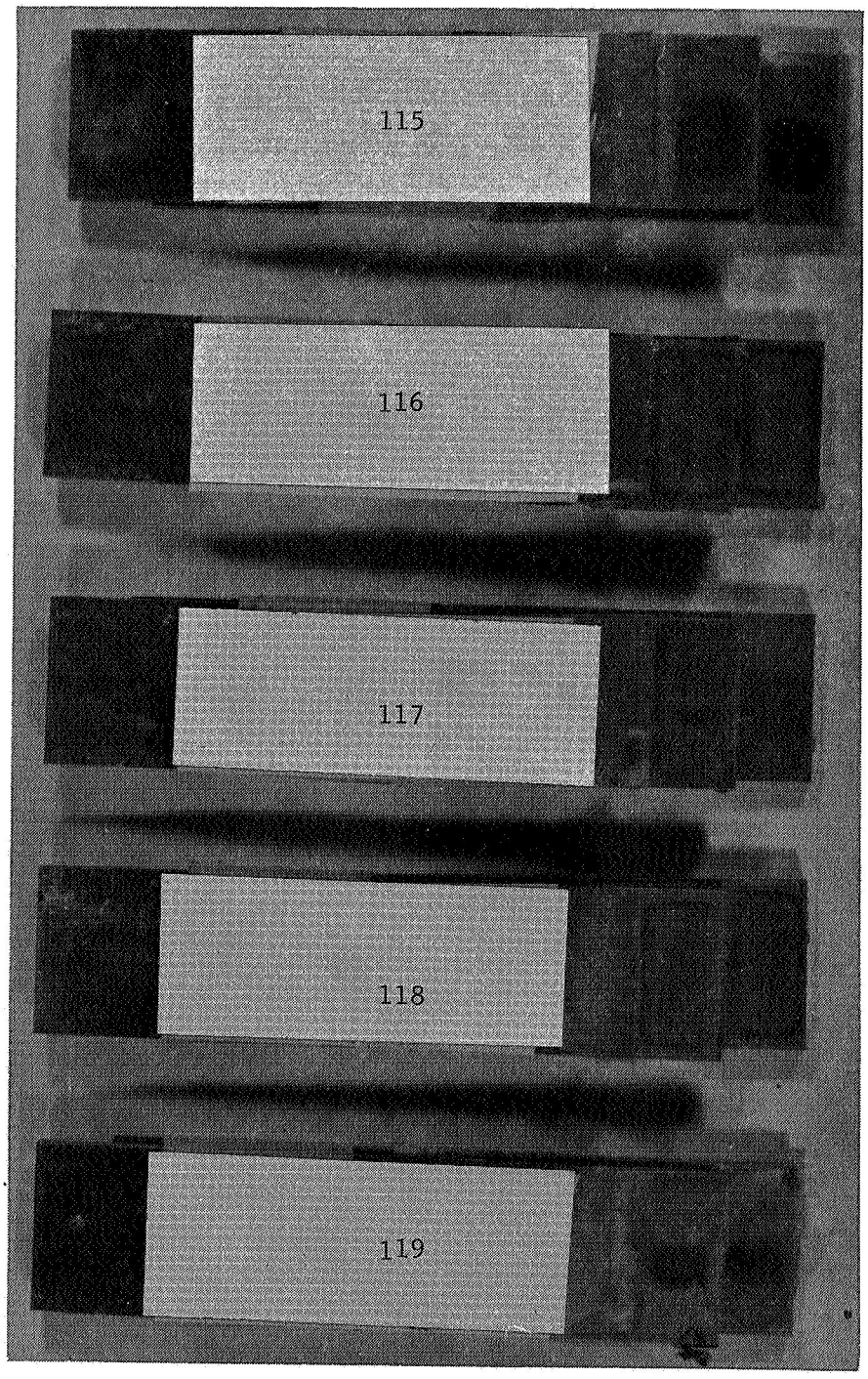

FIGURE 4-12

30 DAYS HUMID AGED SPECIMENS - TESTED AT -320°F θ AL ADHERENDS, NON-PRIMED, BONDED WITH NARMCO 7343/7139 POLYURETHANE ADHESIVE.

TABLE 4-II

Lap Shear Strength of 8 Week Ambient Stored and of 8 Week Humid Aged Aluminum Adherends - Primed With A-1100 Silane Primer - Bonded With Narmco 7343/7139 Polyurethane Adhesive

SPECIMEN NO.	BOND WIDTH (IN)	BOND LAP (IN)	BOND THICKNESS (MILS)	ULT. STRENGTH LOAD (LBS)	ULT. STRENGTH STRESS (PSI)
	[1] (ROOM TEMP. - 8 WEEKS AMBIENT STORAGE)				
1	1.00	.50	1.0	675	1350
2	1.00	.50	1.0	655	1310
3	1.00	.50	1.0	745	1490
4	1.00	.50	1.0	995	1990
5	1.00	.50	1.0	785	1570
AVERAGE					1542
	[1] (-320°F 8 WEEKS AMBIENT STORAGE)				
6	1.00	.50	3.0	5360	10720
7	1.00	.50	1.0	6140	12280
8	1.00	.50	5.0	5980	11960
9	1.00	.50	3.0	5500	11000
10	1.00	.50	1.0	6020	12040
AVERAGE					11600
	[1] (ROOM TEMP. - 8 WEEKS HUMID AGING)				
11	1.00	.50	2.1	495	990
12	1.00	.50	1.8	445	890
13	1.00	.50	1.8	495	990
14	1.00	.50	1.2	470	940
15	1.00	.50	2.0	425	850
AVERAGE					932
	[1] (-320°F - 8 WEEKS HUMID AGING)				
16	1.00	.51	1.6	5000	9803
17	1.00	.51	3.1	4560	9120
18	1.00	.51	2.2	4860	9529
19	1.00	.51	2.1	3920	7686
20	1.00	.51	1.1	3480	6823
AVERAGE					8592

[1] Temp. denotes test temperature.

TABLE 4-III

Lap Shear Strength of 8 Week Ambient Stored and of 8 Week Humid Aged Aluminum Adherends - Primed With Z-6040 Silane Primer - Bonded with Narmco 7343/7139 Polyurethane Adhesive

SPECIMEN NO.	BOND WIDTH (IN)	BOND LAP (IN)	THICKNESS (MILS)	ULT. STRENGTH LOAD (LBS)	ULT. STRENGTH STRESS (PSI)
	[1] (ROOM TEMP. - 8 WEEKS AMBIENT STORAGE)				
21	1.00	.53	1.0	1385	2613
22	1.00	.51	4.0	1140	2235
23	1.00	.48	2.0	885	1843
24	1.00	.50	3.0	1300	2600
25	1.00	.52	1.0	1790	3442
AVERAGE					2546
	[1] (-320°F - 8 WEEKS AMBIENT STORAGE)				
26	1.00	.52	5.0	6820	13115
27	1.00	.51	1.0	6160	12078
28	1.00	.50	3.0	7000	14000
29	1.00	.51	1.0	7000	13725
30	1.00	.52	3.0	5020	9653
AVERAGE					12514
	[1] (ROOM TEMP. - 8 WEEKS HUMID AGING)				
31	.98	.49	2.0	700	1458
32	1.00	.50	2.0	710	1420
33	1.00	.50	1.0	905	1810
34	1.00	.51	1.0	800	1600
35	1.00	.51	2.0	650	1275
AVERAGE					1512
	[1] (-320°F - 8 WEEKS HUMID AGING)				
36	1.00	.50	1.0	4840	9680
37	1.00	.50	1.0	4920	9840
38	1.00	.50	4.0	5100	10200
39	1.00	.50	2.0	4580	9160
40	1.00	.50	1.0	5025	10650
AVERAGE					9786

[1] Temp. denotes test temperature

TABLE 4-IV

Lap Shear Strength of 8 Week Ambient Stored and of 8 Week Humid Aged Aluminum Adherends - Primed With Z-6020 Silane Primer - Bonded With Narmco 7343/7139 Polyurethane Adhesive

SPECIMEN NO.	WIDTH (IN)	Bond LAP (IN)	THICKNESS (MILS)	ULT. STRENGTH LOAD (LBS)	STRESS (PSI)
	[1] (ROOM TEMP. - 8 WEEKS AMBIENT STORAGE)				
41	1.00	.52	3.0	675	1300
42	1.00	.52	2.0	755	1450
43	1.00	.52	1.0	625	1202
44	1.00	.52	3.0	680	1307
45	1.00	.52	1.0	660	1269
AVERAGE:					1305
	[1] (-320°F - 8 WEEKS AMBIENT STORAGE)				
46	1.00	.52	2.0	6390	12288
47	1.00	.51	1.0	5320	10431
48	1.00	.50	3.0	6480	12960
49	1.00	.50	2.0	6160	12320
50	1.00	.50	1.0	6020	12040
AVERAGE:					12008
	[1] (ROOM TEMP. - 8 WEEKS HUMID AGING)				
51	1.00	.50	1.0	FELL APART	
52	1.00	.50	2.0	75	150
53	1.00	.50	5.0	70	140
54	1.00	.50	3.0	140	280
55	1.00	.50	5.0	75	150
AVERAGE					144
	[1] (-320°F - 8 WEEKS HUMID AGING)				
56	1.00	.50	4.0	FELL APART	
57	1.00	.50	14.0	2740	5480
58	1.000	.50	1.0	780	1560
59	1.00	.50	3.0	660	1320
60	1.00	.50	1.0	1340	2680
AVERAGE					2208

[1] Temp. denotes test temperature

TABLE 4-V

Lap Shear Strength of 8 Week Ambient Stored and of 8 Week Humid Aged Aluminum Adhereds - Non-Primed - Bonded With Narmco 7343/7139 Polyurethane Adhesive

SPECIMEN NO.	BOND WIDTH (IN)	BOND LAP (IN)	THICKNESS (MILS)	ULT. STRENGTH LOAD (LBS)	ULT. STRENGTH STRESS (PSI)
	[1] (ROOM TEMP. 8 WEEKS AMBIENT STORAGE)				
61	1.00	.50	4.1	400	800
62	1.00	.50	1.5	465	930
63	1.00	.50	4.1	470	940
64	1.00	.50	2.4	420	840
65	1.00	.50	3.7	320	640
AVERAGE					828
	[1] (-320°F 8 WEEKS AMBIENT STORAGE				
66	1.00	.50	1.2	2090	4180
67	1.00	.50	2.7	3720	7440
68	1.00	.50	3.9	2500	5000
69	1.00	.50	5.5	2800	5600
70	1.00	.50	1.7	3100	6200
AVERAGE					5684
	[1] (ROOM TEMP. 8 WEEKS HUMID AGING)				
71	1.00	.51	2.2	250	490
72	1.00	.51	2.0	135	265
73	1.00	.51	3.1	FELL APART	
74	1.00	.51	2.0	340	667
75	1.00	.51	1.1	265	520
AVERAGE					388
	[1] (-320°F - 8 WEEKS HUMID AGING)				
76	1.00	.50	1.1	1265	2530
77	1.00	.50	2.0	935	1870
78	1.00	.50	1.0	FELL APART	
79	1.00	.50	2.1	785	1560
AVERAGE					1490

[1] Temp. denotes test temperature

TABLE 4-VI

Lap Shear Strength of 30 Day Ambient Stored And of 30 Day Humid Aged Aluminum Adherends - Primed With Z-6020 Silane Primer - Bonded With Narmco 7343/7139 Polyurethane Adhesive

SPECIMEN NO.	BOND WIDTH (IN)	BOND LAP (IN)	BOND THICKNESS (MILS)	ULT. STRENGTH LOAD (LBS)	ULT. STRENGTH STRESS (PSI)
	[1] (ROOM TEMP. 30 DAYS AMBIENT STORAGE)				
80	1.00	.48	9.5	1200	2500
81	1.00	.49	4.0	1290	2632
82	1.00	.50	33.7	605	1210
83	1.00	.50	9.6	975	1950
84	1.00	.49	7.0	875	1786
AVERAGE					2039
	[1] (-320°F 30 DAYS AMBIENT STORAGE)				
85	1.00	.50	4.6	7640	15280
86	1.00	.50	34.4	4020	8040
87	1.00	.50	9.0	5420	10840
88	1.00	.40	7.4	5880	12000
89	.99	.50	4.0	4660	9414
AVERAGE					11115
	[1] (ROOM TEMP. - 30 DAYS HUMID AGING)				
90	.96	.51	34.0	360	735
91	.97	.50	10.3	245	505
92	1.00	.50	8.2	275	550
93	1.00	.50	5.0	165	330
94	1.00	.50	34.9	220	440
AVERAGE					512
	[1] (-320°F - 30 DAYS HUMID AGING)				
95	1.00	.50	10.7	3200	6400
96	1.00	.50	9.2	3220	6440
97	1.00	.51	4.1	1820	3569
98	1.00	.50	33.1	2390	4780
99	1.00	.50	12.2	3000	6000
AVERAGE					5438

[1] Temp. denotes test temperature

TABLE 4-VII

Lap Shear Strength of 30 Day Ambient Stored and of 30 Day Humid Aged Aluminum Adherends - Non-Primed - Bonded With Narmco 7343/7139 Polyurethane Adhesive

SPECIMEN NO.	BOND WIDTH (IN)	BOND LAP (IN)	BOND THICKNESS (MILS)	ULT. STRENGTH LOAD (LBS)	ULT. STRENGTH STRESS (PSI)
	[1] (ROOM TEMP. - 30 DAYS AMBIENT STORAGE)				
100	1.00	.50	19.0	570	1140
101	1.00	.50	13.2	540	1080
102	1.00	.50	13.0	580	1160
103	1.00	.50	5.1	505	1010
104	1.00	.50	12.0	600	1200
AVERAGE					1118
	[1] (-320°F - 30 DAYS AMBIENT STORAGE)				
105	1.00	.50	12.2	2100	4200
106	1.00	.50	15.8	3580	7160
107	1.00	.50	4.2	3360	6720
108	1.00	.50	9.1	3840	7680
109	1.00	.50	9.8	2220	4440
AVERAGE					6040
	[1] (ROOM TEMP. - 30 DAYS HUMID AGING)				
110	1.00	.50	16.3	290	580
111	1.00	.50	3.6	130	260
112	1.00	.50	10.8	315	630
113	1.00	.50	8.4	590	1180
114	1.00	.50	16.0	280	560
AVERAGE					642
	[1] (-320°F - 30 DAYS HUMID AGING)				
115	1.00	.50	3.8	580	1160
116	1.00	.50	15.2	2090	4180
117	1.00	.50	6.9	610	1220
118	1.00	.51	15.0	1470	2882
119	1.00	.50	4.7	515	1030
AVERAGE					2094

[1] Temp. denotes test temperature